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Contributed paper

ALBA XALOC beamline diffractometer table skin concept design

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The XALOC beamline is dedicated to macromolecular crystallography. The position and angle of the X-ray beam at the sample change in horizontal and vertical directions. Consequently, the support of the sample has to follow the beam with two linear and two rotational movements. For this purpose ALBA engineering division has developed a positioning table in house. The main goal of the design was to achieve high resolution, accuracy and stability. Effective resolution and accuracy need adequate actuators and high stability, in the range of 0.1 μm and 0.2 μrad resolution and 1 μm repeatability and first resonance mode $f_0 = 45$ Hz (static and dynamic), for a 1.5 m-long, 1 m-high and 0.6 m-wide table which can support 0.5 tonnes of payload. The actuators were chosen by analytical calculations, whereas the stability is accomplished by a design that minimizes the thermal drifts and avoids the amplification of the vibrations from the ground, increasing the frequency of the resonance modes. The concept is based on a big block of natural granite that acts as a very stable reference base, in terms of thermal expansion and stiffness, and the mechanics are placed as close as possible to this reference. In this manner, the thermal drift is minimized and the stiffness is maximized. Conceptually, the mechanics can be imagined as a skin around the granite base. To reach a proper design several solutions have been analysed, with Finite element analysis (FEA) tools, to validate a compromise solution which has been produced and tested.

1. Scientific case and specifications

XALOC beamline has a relatively simple optical layout, including a channel-cut monochromator and two focusing mirrors, which meet the requirements on stability. As a result, the beam position and angle at the sample change upon X-ray energy and configuration. Taking this into account, the positioning table of the sample is specified to reach the ranges summarized in table 1.

2. Conceptual design and development

To meet the requirements in resolution and stability, which have high priority, a big block of natural granite, as tall as possible to be as close as possible to the sample, is used. The stages mounted on this granite are designed to be as close

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	Vertical translation	Pitch	Horizontal translation	Yaw
Range	70 mm	−2,5 to +12.5 mrad	60 mm	−2.5 to +12.5 mrad
Resolution	1 μm	2 μrad	5 μm	10 μrad
Repeatability	1 μm	2 μrad	5 μm	10 μrad
Resonance f_0	>40 Hz	>40 Hz	>40 Hz	>40 Hz
Weight: not specified, payload: 500 kg				
Estimated dimensions: length: 1600 mm, width: 500 mm, height: 1100 mm				

TABLE 1. Specification of the diffractometer and sample table

as possible to the granite faces, so that the mass lever arms are minimized and the stiffness is optimized.

The vertical translation is performed by a front and a back plate connected by a horizontal plate giving an inverted U form around the granite. The pitch is achieved by a differential movement of front and back plates and carving a flexure on their upper end (figure 1*a*).

The transversal movement is performed by conventional precision linear stage meanwhile the yaw is achieved by circular guides, see figure 1(*b*). The rotational articulation on the motion system of the yaw is relieved by a small flexure. All four motion systems are based in preloaded re-circulating ball screws, reducers with big reduction ratio and stepper motors.

All figures show the simplified model used for the FEA, in which (*a*) the guides are modelled with a soft young modulus material and sliding contacts and (*b*) the ball screws and their supports are modelled as rigid springs for dynamical calculations. Elements on top of the table were also included in the model (figure 2*a*). The final detailed design of the table is shown in figure 2(*b*). The expected, calculated values are summarized in table 2.

The maximum stress calculated with Ansys on the vertical flexures is 280 MPa, and 400 MPa for the yaw flexure. Special high elastic limit steel is chosen for these special parts.

The reaction force calculated by this FEA to perform the pitch on the ball screws is about 8340 N which means that only 590 N are needed to bend the vertical flexures (figure 3). The reaction force to bend the yaw flexure is about 150 N.

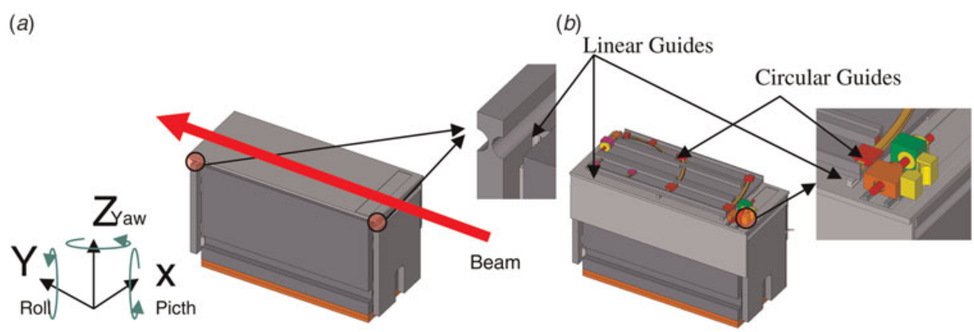

FIGURE 1. (*a*) Vertical translation and pitch and (*b*) transversal translation and yaw.

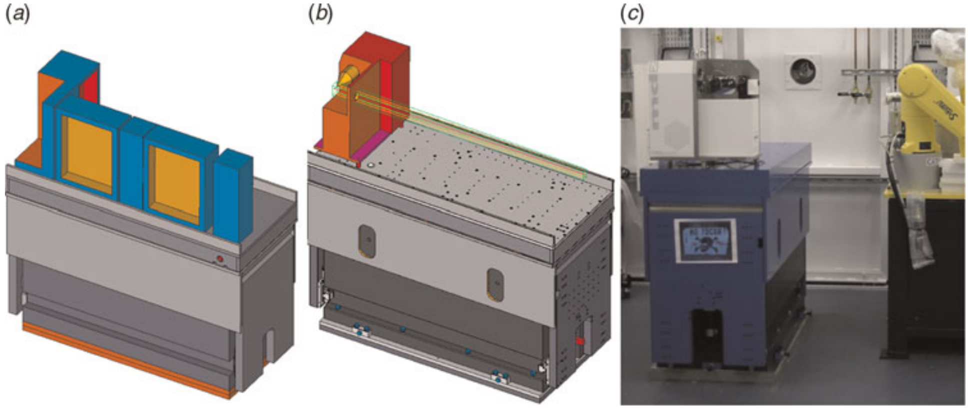

FIGURE 2. (*a*) Simplified, conceptual, design for FEA; (*b*) final detailed model; (*c*) macromolecular crystallography beam line end station, BL 13 XALOC.

	Vertical translation	Pitch	Horizontal translation	Yaw
Range	70 mm	15 mrad	60 mm	15 mrad
Resolution	0.1 μm	0.2 μrad	0.4 μm	0.4 μrad
Repeatability	1 μm	2 μrad	1 μm	10 μrad
Resonance f_0	58 Hz	68 Hz	45 Hz	45 Hz

Weight: 1550 kg, payload: 500 kg
Overall dimensions: length: 1520 mm, width: 620 mm, height: 1100 mm

TABLE 2. Diffractometer table-calculated performances

3. Production, installation and final results

This is a full in-house design and development project at Consortium for the Construction, Equipping and Exploitation of the Synchrotron Light Laboratory (CELLS). The production of the parts has been outsourced to workshops near to the facility. Finally, the table has been mounted and installed at ALBA.

Metrology tests were performed by the metrology group at ALBA using a linear interferometer ML10 Gold edition (Renishaw, UK) (table 3). A dummy mass of

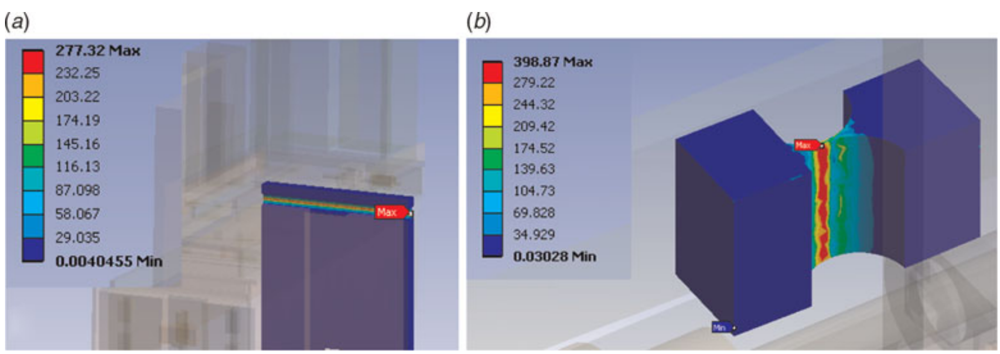

FIGURE 3. (*a*) Vertical flexure stress at 7.5 mrad and (*b*) horizontal flexure stress at 7.5 mrad.

Specified calculated results	Vertical translation	Pitch	Horizontal translation	Yaw
Range	70 mm	15 mrad	60 mm	15 mrad
	70 mm	15 mrad	60 mm	15 mrad
	>70 mm	>15 mrad	>60 mm	>15 mrad
Resolution	1 µm	2 µrad	5 µm	10 µrad
	0.1 µm	0.2 µrad	0.4 µm	0.4 µrad
	0.2 µm	0.53 µrad	0.31 µm	0.38 µrad
Repeatability	1 µm	2 µrad	5 µm	10 µrad
	1 µm	2 µrad	1 µm	2 µrad
	2.52 µm	0.89 µrad	0.52 µm	0.76 µrad
Resonance f_0	>40 Hz	>40 Hz	>40 Hz	>40 Hz
	58 Hz	68 Hz	45 Hz	45 Hz
	43 Hz	43 Hz	Not measurable	Not measurable

Weight: 1550 kg, payload: 500 kg
Overall dimensions: length: 1520 mm, width: 620 mm, height: 1100 mm

TABLE 3. Comparison of the results of the metrology tests of the diffractometer table

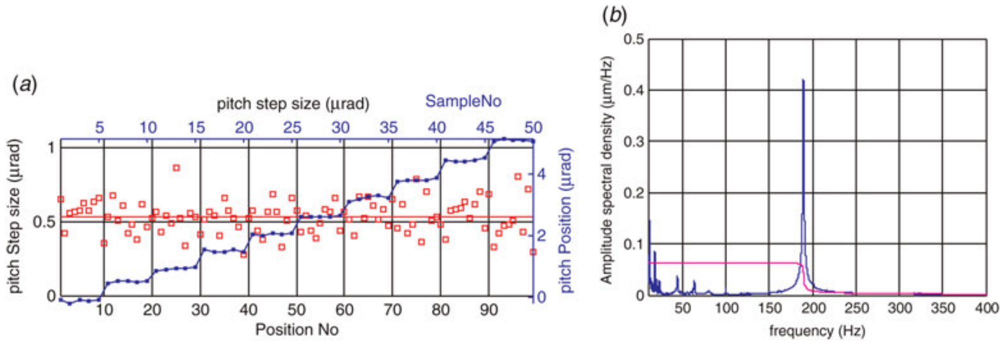

FIGURE 4. (*a*) Pitch resolution and (*b*) vertical vibrations calculated from the linear interferometer measurements. Square points and horizontal line: Step size for each one of the steps taken during the test. Steps line: Example of the 10 first steps of the scan (referred to the top and right axis).

500 kg was fixed on the table for the tests. Results fully meet the specifications, including critical parameters such as vertical and pitch resolutions and resonance frequencies. An example of these performances is shown in figure 4.

4. Conclusions

The payload mass, and dimensions, resolution and stiffness (vibration behaviour) are requirements that are not usually met together, but the results demonstrate that with a good balance between rigidity and dimensions, choosing the proper components and placing all the elements as compact as possible on a very good reference base, all four specified numbers can be achieved together.

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